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WARHEAD PARAMETRIC STUDIES AGAINST A
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by

Peter W. Taylor

December 1980

Thesis Advisor:

G.H. Lindsey

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Warhead Parametric Studies Against a
Generic Cruise Missile

by

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Lieutenant, United States Navy
B.S. Florida Technological University, 1972

Submitted in partial fulfillment of the
requirements for the degree of

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from the

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ABSTRACT

This study utilizes the SCAN computer program to determine the overall effectiveness of a fragmentation warhead against a generic cruise missile target. The objective of the SCAN program is to predict the probability that a target will survive an attack by a missile armed with a fragmentation warhead. Several warhead parameters were investigated, including warhead radius, explosive weight, fragment size and warhead spray pattern. The P_k is presented in various figures and tables, where it is discussed in relation to miss distance, triggering position, elevation and pitch angles, warhead radius, and fragment size. The computer data resulting from the many runs of the SCAN program considered here is a helpful tool for the warhead designer, or student of warhead design, since it can give guidance on the selection of many of the crucial parameters that make the warhead effective against a given target.

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I. INTRODUCTION

Missile designers and other persons interested in studying warheads can make use of computer programs that provide a concise and detailed picture of the exact damage that a specifically designed warhead can produce on a specified target. Two of the most common programs in use today are the ATTACK program and the SCAN program.

The primary objective of the ATTACK program [Ref. 1] is to predict the ability of a missile to detect and destroy an airborne target. This program provides a probability of kill (P_k) assessment for:

- (1) direct hits
- (2) blasts
- (3) multiple fragments (structural)
- (4) single fragment (component) damage mechanisms

ATTACK uses an approach based upon the establishment of vulnerable area data for each component in the target model as a function of encounter geometry, aspect angle, warhead fragment weight and fragment impact velocity. It requires one geometric model for each of the four possible damage mechanisms. A fifth stick model representation is needed for the fuzing portion of the program, which depends upon the type of target encountered.

The final encounter conditions are specified by the user. The missile may be oriented with respect to a coordinate system fixed in the target or one fixed on the missile, or one that is stationary. The user may specify a missile miss distance or require that the program generate it randomly from a Gaussian distribution. A standard deviation can also be provided by the user for miss distance.

The objective of the SCAN program, [Ref. 2] is to predict the probability that a target will survive an attack by a missile armed with a fragmentation warhead. P_k is reported for three different damage mechanisms:

- (1) direct hit
- (2) blast
- (3) single fragment damage

By utilizing the target geometric models, the SCAN program makes computations for all fragments to determine fragment impacts upon the component shapes. Encounter conditions are constructed from one of three possible choices:

- (1) Define a trajectory by fixing the initial missile range from the target and by fixing the orientation of the missile relative to the target.
- (2) Input a miss distance.
- (3) Input a circular error probable (CEP).

SCAN has the advantage of having greater flexibility for statistical variation in the encounter geometry; also, the target may be defined much more accurately because of the

greater data input capability. The major disadvantage of SCAN is in its inflexibility for extensive fuze modeling, as is found in ATTACK. ATTACK has the disadvantage of having very limited supporting data for input runs and is at the present time being phased out to be replaced by an improved program which is being developed.

The major reason that SCAN was used for this study was the ready availability of model data for computer runs. It combines all the elements of survivability analysis into one program by using warhead fragments to generate shot line data. It is a very accurate method because component damage can be assessed using fragment striking velocities, fragment mass and target aspect angles. This results in an opportunity to analyze a target's survivability, giving detailed damage estimates at system, subsystem and component levels. This data was used in evaluating performance and in making various trade-off studies between different warhead parameters.

For this thesis all input data fed into the SCAN program was directed at a target which equated with a generic cruise missile. To limit the number of parameters investigated, the study was confined to hard steel fragmentation warheads, constant spray angles of fragments, constant l/d ratio and a single explosive type. The variables included fragment size, diameter of the warhead, pitch angle and elevation of the missile with respect to the target and miss distance.

Computations were performed for all fragments which hit the target, some of which did not do vital damage; nevertheless, the relationship between target structure and warhead fragmentation patterns could be studied. These results can be used by warhead designers during the conceptual design stage and then compared with experimental test results. The computer output data was utilized in constructing graphs and tables, which were used to predict the terminal effectiveness of a missile warhead against a cruise missile target. The measure of effectiveness of the missile warhead was defined as the probability that a properly deployed missile would inflict a specific degree of damage on the target. The results were organized for warhead design, weapon system evaluation and fuze optimization.

II. BACKGROUND

A. TARGET

The target chosen for analysis was a generic cruise missile. The cruise missile configurations used do not represent actual conceptual missile design situations; instead, a generic model was selected to reflect the size, shape and position of typical fuselage sections, wings, stabilizers and engines. Structural properties of the generic target were selected from existing example missiles of similar construction.

B. WARHEAD USED IN SCAN

The missile warhead used in this study was generally similar to existing air-to-air or surface-to-air missile warheads.

1. Warhead Elements

The basic warhead consists of three parts: explosive payload, fuze and the safety and arming device. Variations in warhead type are obtained by altering any or all three elements. The primary element of the warhead is the explosive payload. For example, a fragmentation warhead operates by bursting a metal case with a high-explosive charge. Upon explosion, the container is shattered into thousands of fragments that fly out at high velocities and are capable of damaging targets at considerable distances from the point of detonation.

Blast and blast fragment damage mechanisms can kill the target by nearby detonations; for this reason, this type of warhead is very effective against airborne targets. Usually the warhead does not penetrate the target, but is detonated by the fuze at a distance that allows the full destructive effect to be realized. SCAN yields the P_k resulting from detonations at distinct points in space about the target under specified encounter conditions.

The fuze is that part of the warhead that initiates detonation. In guided missiles the fuze is referred to as the target detection device (TDD). For an attack to be effective, detonation must occur at the time during the missile's trajectory that will cause maximum damage to the target. The optimum time of detonation is determined by the encounter geometry between the target involved and the warhead. If effectively designed, the fuze always recognizes and initiates detonation at the optimum time. The kill probability of a missile depends upon the reliability of the missile, the guidance accuracy of the missile system, the fuzing, and the warhead lethality. The assumption for this study was that the guidance system delivered the warhead to the correct point in order to achieve a specified P_k , and that the fuze detonated the warhead at that point.

The primary purpose of the safety and arming device (S&A) is to insure the transfer of energy from the fuze to the payload at the proper time and yet prevent the energy transfer from occurring prior to the optimum moment.

2. Warhead Design

Many variables influence warhead design. Several are listed below:

- a. Threats
 - target construction
- b. Encounter conditions
 - aim point
 - miss distance
 - aspect angle
- c. Weight and volume constraints
- d. Kill level/vulnerability models
- e. Fuzing capability
- f. Cost
- g. Complexity

During the Conceptual design and early definition, major trade-offs are made in warhead design parameters such as radius, length, fragment size, initial velocity, etc. to derive optimum performance. In the conceptual phase, warhead design parameters change as development continues and trade-offs are made. The initial design of a warhead is usually based upon the type of target, or targets, specified, the accuracy of the guidance system, the type of kill desired and the volume constraints placed on its physical size, and it may very well size the whole missile.

The diameter of a missile is determined by one of three driving forces:

- (1) warhead size
- (2) propulsion system
- (3) guidance seeker diameter

In this thesis the seeker and the propulsion system were not considered, but the focus was on warhead design by varying warhead parameters as the means for design development.

3. Warhead Sizing

One of the important parameters in warhead sizing is the length to diameter ratio (l/d). From historical data, the optimum length to diameter ratio for a cylindrical warhead (for an air-to-air or surface-to-air missile warhead) lies between 2.0 to 3.0. Varying the warhead radius for a given l/d ratio and case thickness, alters the charge to mass ratio which causes the fragment initial velocity to change, which in turn will effect the kill probability. In developing the warhead models used to derive the probabilities discussed in the following pages, a case thickness of 0.4 inches and a ratio of $l/d = 2.5$ was used. The outside diameter of the warhead case was varied from 6.0 inches to 9.92 inches. The length was increased accordingly in order to hold the l/d ratio constant.

4. Fragmentation Warhead

The fragmentation warhead is a warhead specifically designed to emit a maximum number of uniformly sized fragments having optimum penetration properties. The blast

effect, which accompanies the emission of the fragments, is a secondary effect and will not be considered in the assessment of the effectiveness of the fragmentation warhead.

Fragments can cause damage in many ways. They can cause structural damage in the way that a bullet does by puncturing and cutting structures. The structures may either be severed, if the density of the fragments is sufficiently high, or they may be so weakened that aerodynamic loads cause breakup of the structure. If the fragments strike the target, a high velocity fragment will give up a large amount of energy in a short time to the target. If the target struck were fuel, it may be ignited; if the target were the high explosive in a warhead, it may be detonated. If it were a structural member, it may be shattered or at least weakened.

Fragmentation warheads for air-targets usually share certain common configurations. They are constructed and mounted to be symmetric with the longitudinal, or roll axis, of the missile. The static spray pattern is in a plane perpendicular to the roll axis of the missile. The particular spray pattern achieved with a warhead of given construction may be varied to some extent by the choice of the point within the warhead where detonation takes place. The purpose of shifting the initiation point from the warhead center is to throw the center of the beam forward or aft as required to adjust the fragment pattern.

It is desirable to control the size of the fragment within certain limits; since fragments that are too small are ineffective, and fragments that are too large have low velocities and do not carry far. In the warhead model design under consideration, the fragments were considered to be produced by scoring the warhead case so that either 60, 105, 150, or 240 grain rectangular fragments were produced; however, multiples and fractions of this weight may frequently be encountered at the extreme polar zones. Fragment area densities, or the number of fragments per zone, can be approximated from postulating the type of warhead initiation used. All data input for SCAN concerning the warhead assumed it to be a center initiated device, producing a maximum fragment beam at a static spray angle of 75 degrees, as illustrated in Figure 1.

The majority of fragmentation warheads designed for use against aerial targets are cylindrical in shape to project an effective fragment area density on the target. This shape also forms an efficient package because it conforms well to the aerodynamic configuration of the missile.

The warhead fragmentation characteristics used were symmetric with respect to the warhead centerline (i.e., no shaped charges or aimable warheads.) The warhead description required the following parameters to be considered:

1. Number of static spray polar zones.
2. Fragment mass.

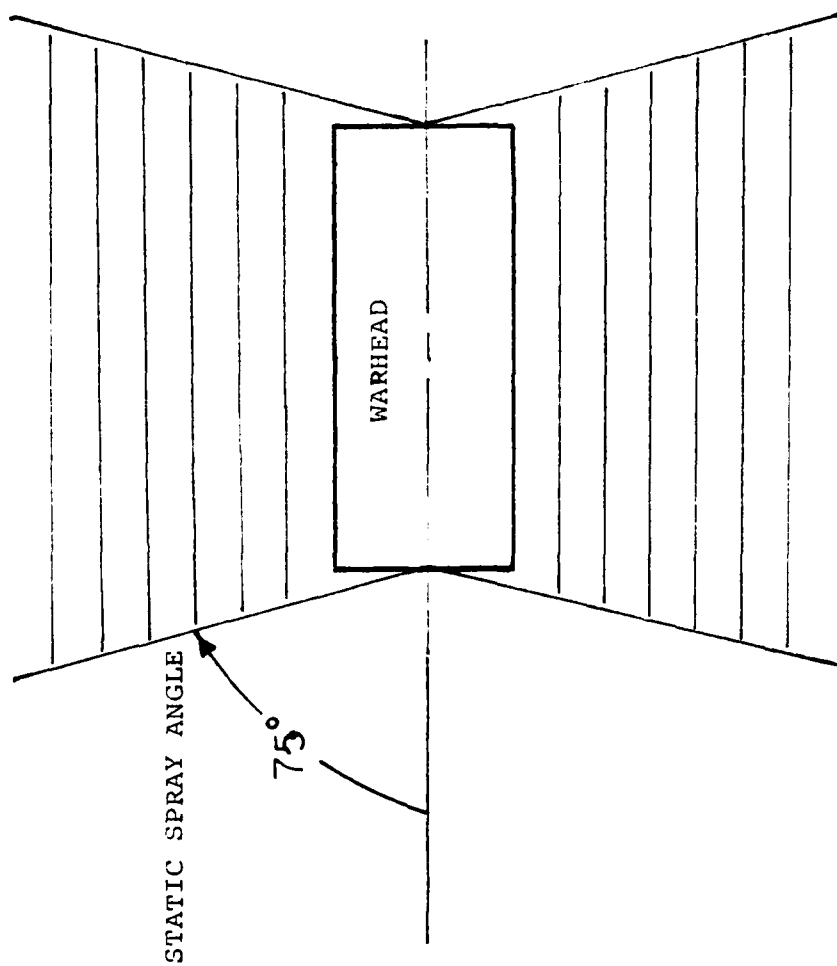


Figure 1. Warhead Static Spray Angle.

3. Fragment initial velocity at each zone boundary.
4. Number of fragment of a given mass for each polar zone.
5. Fragment material.
6. Fragment shape.

Fragments originating from detonation of high explosive (HE) warheads are usually steel, but may be more dense materials such as tungsten or depleted uranium, which may be more lethal than steel fragments under certain circumstances. In the following examples and graphs, rectangularly shaped steel fragments were considered. Such fragments damage missile components primarily through penetration and the effects of perforation.

Fragment impact velocities between 4,000 and 10,000 fps were studied. The characteristics of a steel fragment make it effective in causing damage to lightly constructed components; e.g. control rods, fuel lines, structural members, etc. When a fragment strikes the skin, or any other component of a missile at high speed (4,000 fps or greater), the fragment tends to break up into smaller fragments which are less lethal individually than the original fragment. This is not included in the program as a damage mechanism. Also, when a steel fragment is traveling at high speed, it can cause a flash on impact with the missile skin or some other material, which can initiate a fire if fuel is exposed. This type of kill was not accounted for either.

There exist other important factors which should be considered in evaluating the performance of conventional fragmentation warheads. For the sake of brevity, we will simply mention them here without further discussion:

- . Burst location and altitude of warhead
- . Striking velocity and attitude of fragement
- . Penetration capability
- . Residual mass and velocity
- . Number of fragments entering a vital compartment or component.

III. PROGRAMMING INFORMATION

A. INPUT

Utilization of the SCAN program requires that the following data be input:

- a) specification of the physical target
- b) structural characteristics of the target
- c) designation of appropriate damage criteria for the class and type of kill of the target
- d) definition of the missile warhead (See detailed data in Table I)
- e) specification of the missile warhead/target geometry and intercept kinematics.

B. TYPICAL CASE DATA

Required data for utilization of the SCAN program is described as follows:

Missile trajectory type = 1 (fixed trajectory with a user specified missile starting position measured from the target center of gravity).

Sample size = 50 missile warhead/generic cruise missile encounter situations.

Missile roll angle = 0 degrees

Missile pitch angle = 0 degrees

Missile yaw angle = 0 degrees

Missile speed = 2,300 feet per second

TABLE I
WARHEAD FRAGMENTATION DATA

POLAR ZONE 75° - 105°
 l/d RATIO 2.5
 CASE THICKNESS (t) 0.4 in.
 EXPLOSIVE MATERIAL (TNT) $\rho_e = 1.59 \text{ g/cm}^3$
 FRAGMENT MATERIAL (HARD STEEL) $\rho_c = .286 \text{ lb/in}^3$
 FRAGMENT SHAPE RECTANGULAR
 $\sqrt{2E}$ 7600 ft/sec

| GRAIN SIZES | NO. OF FRAG | V_i (FPS) | r_w (in.) | LENGTH (in.) |
|-------------|-------------|-------------|-------------|--------------|
| 60 | 3500 | 5180 | 3.0 | 15.0 |
| 105 | 2000 | 5180 | 3.0 | 15.0 |
| 150 | 1400 | 5180 | 3.0 | 15.0 |
| 240 | 534 | 5180 | 3.0 | 15.0 |
| 60 | 5461 | 5876 | 4.0 | 20.0 |
| 105 | 3120 | 5876 | 4.0 | 20.0 |
| 150 | 2187 | 5876 | 4.0 | 20.0 |
| 240 | 1365 | 5876 | 4.0 | 20.0 |
| 60 | 9906 | 6394 | 4.96 | 24.8 |
| 105 | 5660 | 6394 | 4.96 | 24.8 |
| 150 | 3967 | 6394 | 4.96 | 24.8 |
| 240 | 2476 | 6394 | 4.96 | 24.8 |

Missile angle of attack = 0 degrees
Standard deviation of angle of attack = 3.0 degrees
Missile elevation angle = 0 degrees
Standard deviation of elevation angle = 1.0 degrees
Missile azimuth angle = 180 degrees (head on approach)
Standard deviation of azimuth angle = 0 degrees
Encounter altitude = 10,000 feet
Missile aimpoint vector = c.g. of missile to c.g.
of target
Miss distance specified = various (expressed in feet)

C. ENCOUNTER GEOMETRY

Basic geometry defining the target/warhead engagement is illustrated in Figure 2. As shown, the target is oriented along the y axis with its left wing directed in the negative x axis. It has a velocity in the positive y direction.

The trajectory of the warhead is fixed relative to the target by the selected encounter condition. The approach direction is defined by azimuth (AZ) and elevation (EL) angles relative to the target coordinate system. See Figure 3. The user can determine his own set of aspect angles or use the default values provided in the SCAN program.

D. OUTPUT

The output from the SCAN program presents the results of each simulated warhead/cruise missile encounter, and consists of three output subgroups:

1. Summary of terminal encounter parameters

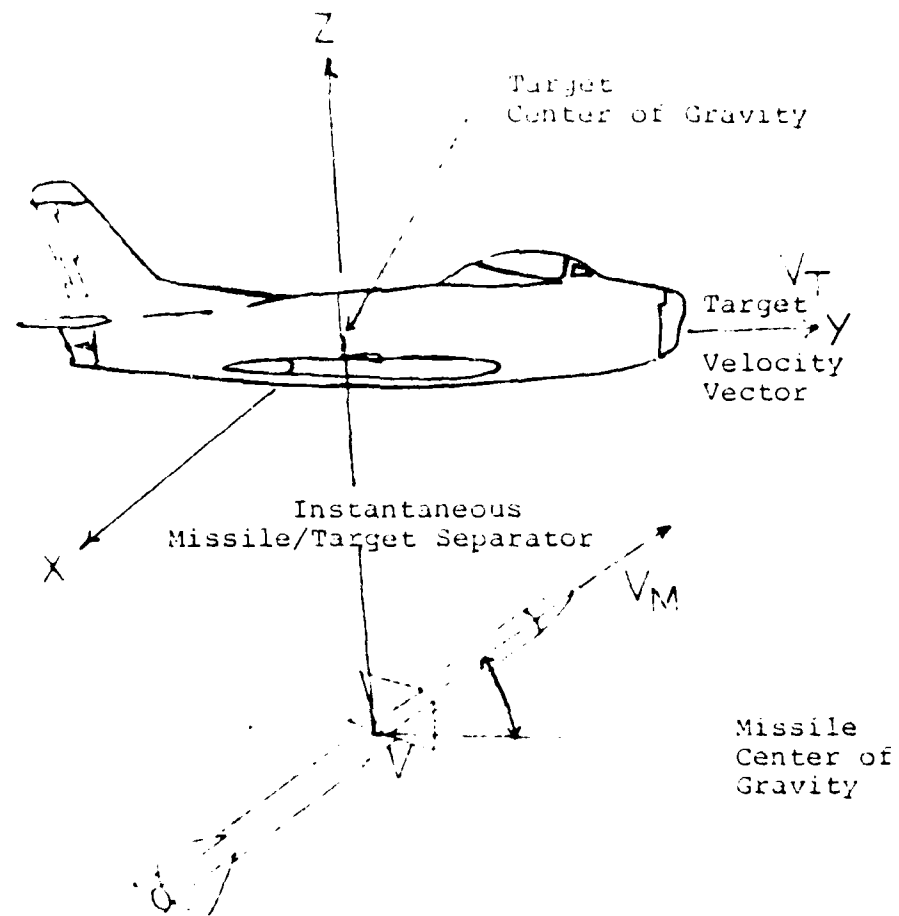


Figure 2. Encounter Condition Geometry.

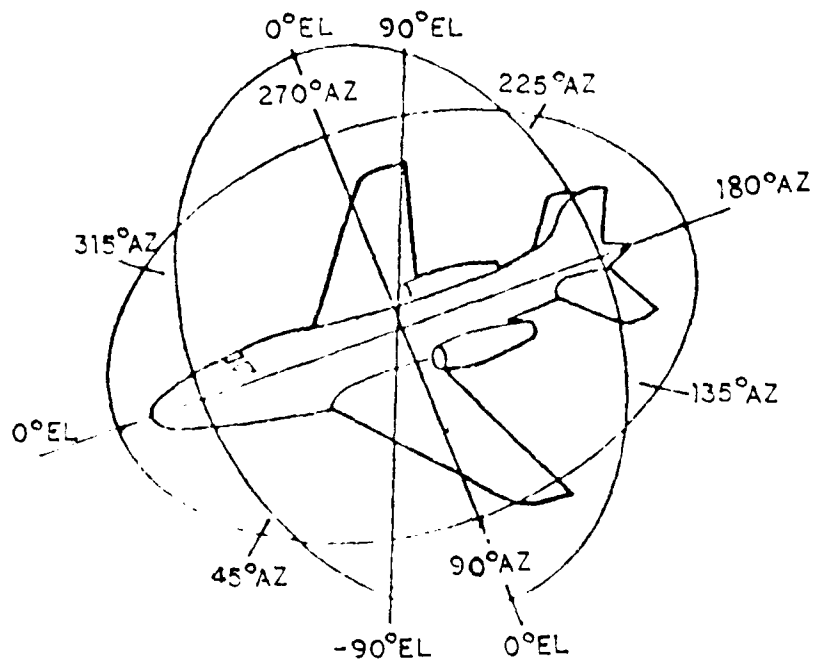


Figure 3. Elevation and Azimuth Encounter Conditions.

2. Missile component damage summary

3. Survival probabilities

In order to have meaningful statistical results, sample sizes of fifty missile encounters were examined and used to develop the graphs.

IV. EVALUATION

The ultimate objective of the evaluation was to examine the influence of to ensure that various warhead parameters on the missile's capability of destroying the target when it is used in actual operation. The computer simulated endgame approximates as closely as possible the encounter conditions under which the warhead functions in actual use. The results obtained through the use of the SCAN program show a warhead versus a small and relatively soft target. The generic cruise missile was used in order to obtain data directly applicable to the design and development of a warhead that would be effective against this type of target.

Because of the great number of factors that influence the results obtained in detonation of the warhead, it is necessary that the details of the encounter conditions of the various computer runs be specified. Realistic situations have been used to evaluate the warhead parameters and although actual encounters may differ, they should not effect the final conclusions.

Factors that must be specified are details of the encounter conditions, such as target and missile orientation, relative position of target and missile, parameters of the warhead and vulnerability characteristics of the target. Static versus dynamic situations will give results quite

different from each other, and all encounters in this study were dynamic.

It is apparent in any situation there is no single, simple target which is adequate for the purpose of determining the perfect fragmentation warhead for all uses. Some targets are more susceptible to fragmentation warheads, while others are more susceptible to expanding rods or aimable warheads. Only by the use of a series of targets can the overall effectiveness of the warhead be determined, but its effectiveness against a given target can be judged by computer endgame results which involve a detailed geometric description of the target and its structural components.

Through the SCAN program, enough encounter conditions were repeated until sufficient data were obtained to express the probability that a given target might be destroyed under specified conditions.

A. EXPLOSIVE WEIGHT VERSUS MISS DISTANCE

For the first study, a generic cruise missile was used with the design configuration shown in Figure 4:

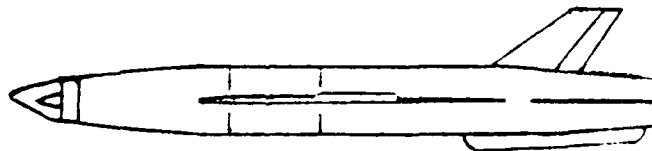


Figure 4. Generic Target.

The target was approximately 25 feet long and constructed mainly of aluminum. The structural components, flight profile and aerodynamic configurations were the same in all computer runs.

The major systems that were evaluated for P_k included engines, airframe structure, warhead, hydraulic systems, guidance system and fuel system.

The principal data recorded are as follows:

1. Whether a K-kill (damage to the target which causes it to begin to fall within 30 seconds of the missile warhead burst) [Ref. 3] is obtained or not.
2. The distance of detonation of the warhead from the target.

A quantitative relationship between the miss distance of the target and the explosive weight required to destroy the target was obtained. This relationship is illustrated in Figure 5. As the miss distance increases, for most targets, the damage effect caused by fragments decreases because the fragment area density decreases. The fragmentation warhead is producing an expanding cylindrical shell of uniform thickness composed of many small fragments. Since the surface area of the cylindrical shell increases in direct proportion to its radius, the fragment area density decreases inversely with the square of the radius. The P_k curves in Figure 5 tend to flatten out however for any explosive weight above approximately 50 lbs., indicating

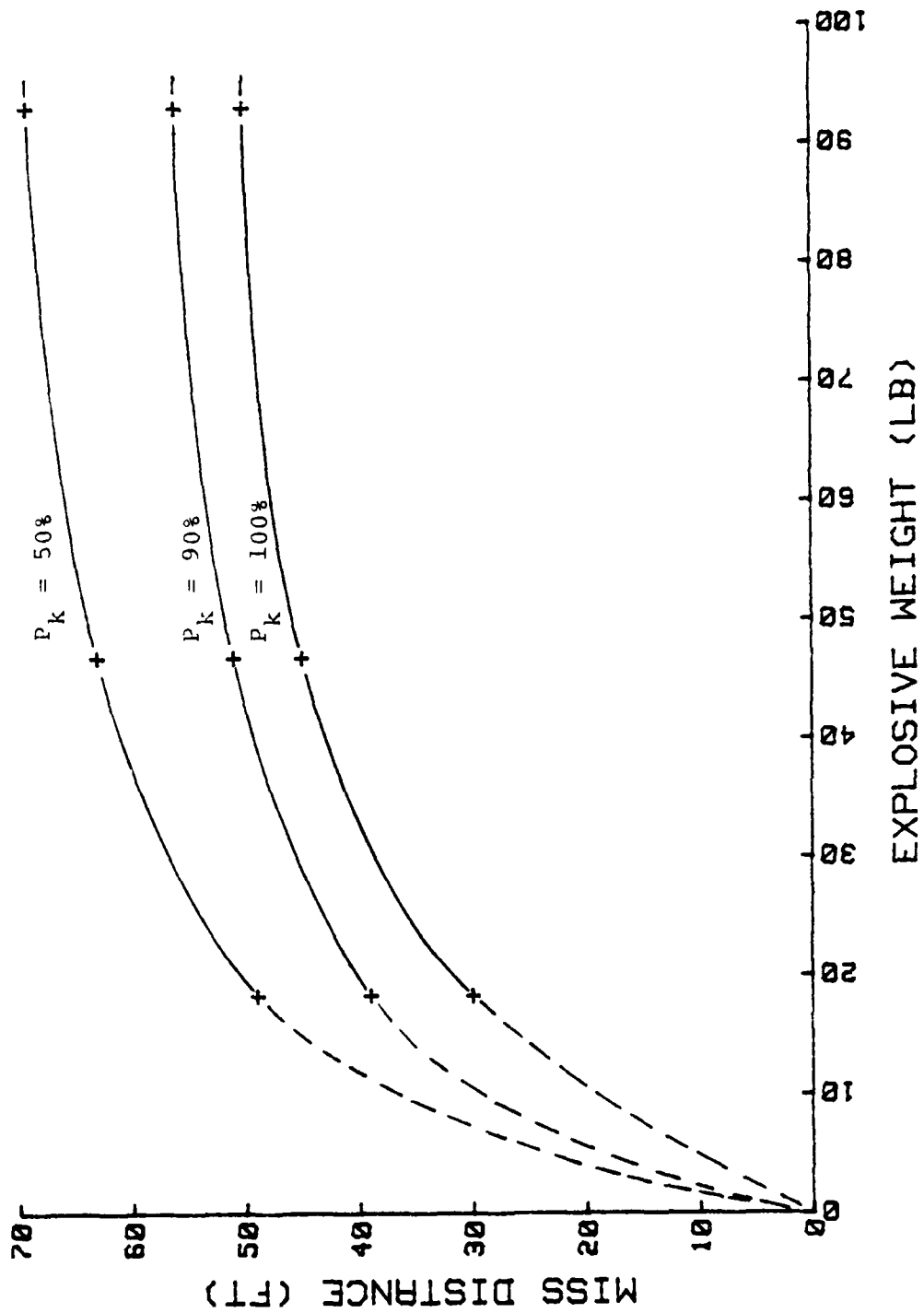


Figure 5. Explosive Weight vs. Miss Distance.

little or no increase in miss distance for any further increase in explosive weight. This is due to the nature of the soft cruise missile target which would be killed within approximately 43 feet regardless of increased explosive weight. Adding explosive weight merely increases the velocity of the fragments themselves, and since the soft target has very little or no redundancy in its systems and components, a hit by even a relatively few fragments will result in a P_k of 100% within approximately 43 feet. If we accept a probability of kill of only 50%; then based on 50 lbs. of explosive, the distance would be approximately 63 feet, due to the decrease in fragment area density.

B. VARIATIONS IN PITCH AND ELEVATION ANGLES

The next scenario is a head-on encounter with the warhead being pitched through 15 different angles from $+70^\circ$ to -70° , at each elevation angle which was varied in 10° increments from 0° to 90° in the vertical plane of the target.

All test runs were made with a fragmentation warhead having fragments sized at 105 grains. There were 450 encounter conditions studied, but only those encounter conditions which actually resulted in a kill were recorded on the graph of Figure 6. The percentage of the 450 encounters in which the warhead kills the target from a given direction and attitude are summarized in Table II. Note that the warhead is detonated at three locations ranging from 30 to 50 feet from the target.

These analyses seek to establish the desired elevation and pitch angle, with reference to the target, which optimizes the P_k . From the data appearing in Table II, it is apparent that the most desirable approach to the target would be from an elevation angle of 30 to 90 degrees with reference to the target. The type of information extracted and analyzed in Figure 6 is concerned with the direction, relative to the target, from which the fragments cause damage. These data serve as the basis for estimates concerning the kill probability that can be expected from all pitch angles at a given elevation angle for distances up to 50 ft. Such estimates are useful in design decisions regarding fragment pattern and fuzing modes to use against a target.

TABLE II
PERCENTAGE KILL VS WARHEAD ELEVATION ANGLE

| Elevation Angle | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
|----------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Number of Detonation | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 |
| Number of Kills | 2 | 7 | 12 | 15 | 20 | 18 | 20 | 20 | 15 | 16 |
| Percent Kills | .04 | .16 | .27 | .33 | .44 | .40 | .44 | .44 | .33 | .36 |

These conclusions do not cover all possibilities that can be envisioned, but they indicate the general order of warhead effectiveness for given encounter conditions between the warhead and target. For example, missiles in a relative

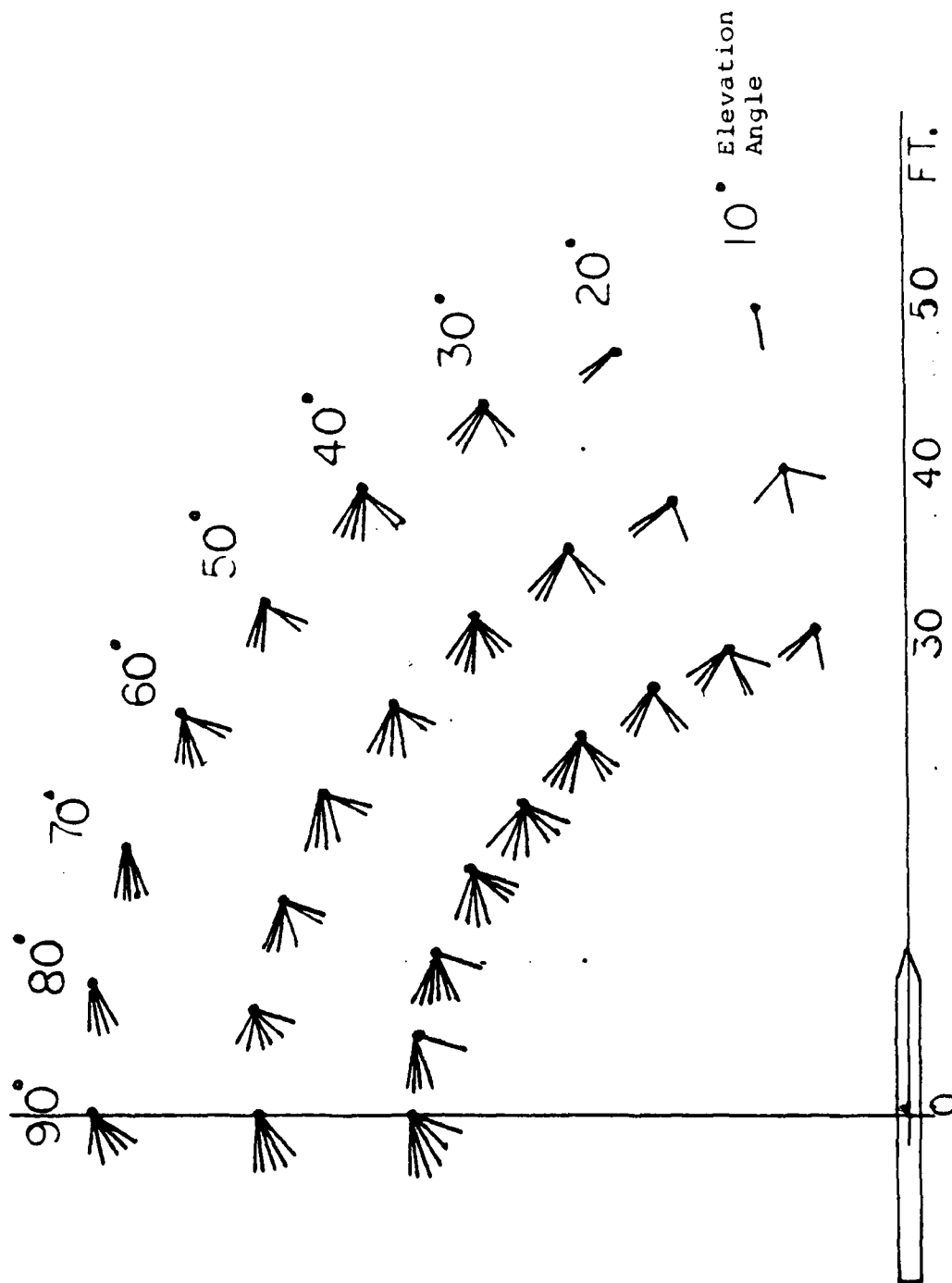


Figure 6. Variations in Pitch and Evaluation Angles.

head-on encounter condition, with a pitch angle of 0 degrees to ± 20 degrees, a fragmentation warhead of the nose spray type will be more efficient than that of the side spray type, since the nose spray warhead will concentrate fragments in a forward direction, directly in the path of the oncoming target.

A manual plot of a single encounter for verification purposes was made by choosing a single model and single encounter geometry. An example of one of these plots from Figure 6 is illustrated in Figure 7. This particular encounter is for a head-on scenario with the detonation point 7.0 feet above the target along the trajectory flight path. The pitch angle of the warhead is 10 degrees with a detonation distance of 40 feet from the target.

Fragment dynamic spray angles were calculated from the following equation:

$$\theta = \tan^{-1} \left[\frac{V_o \sin \theta}{V_r + V_o \cos \theta} \right]$$

V_o = initial fragment velocity

V_r = relative encounter velocity

θ = corresponding static spray angle

When the moving warhead detonates, the fragment which are ejected in a static polar zone will be projected at an angle closer to the missile axis as a result of adding the missile velocity to the static fragment spray velocity. If the missile warhead has an angle of attack or pitch angle

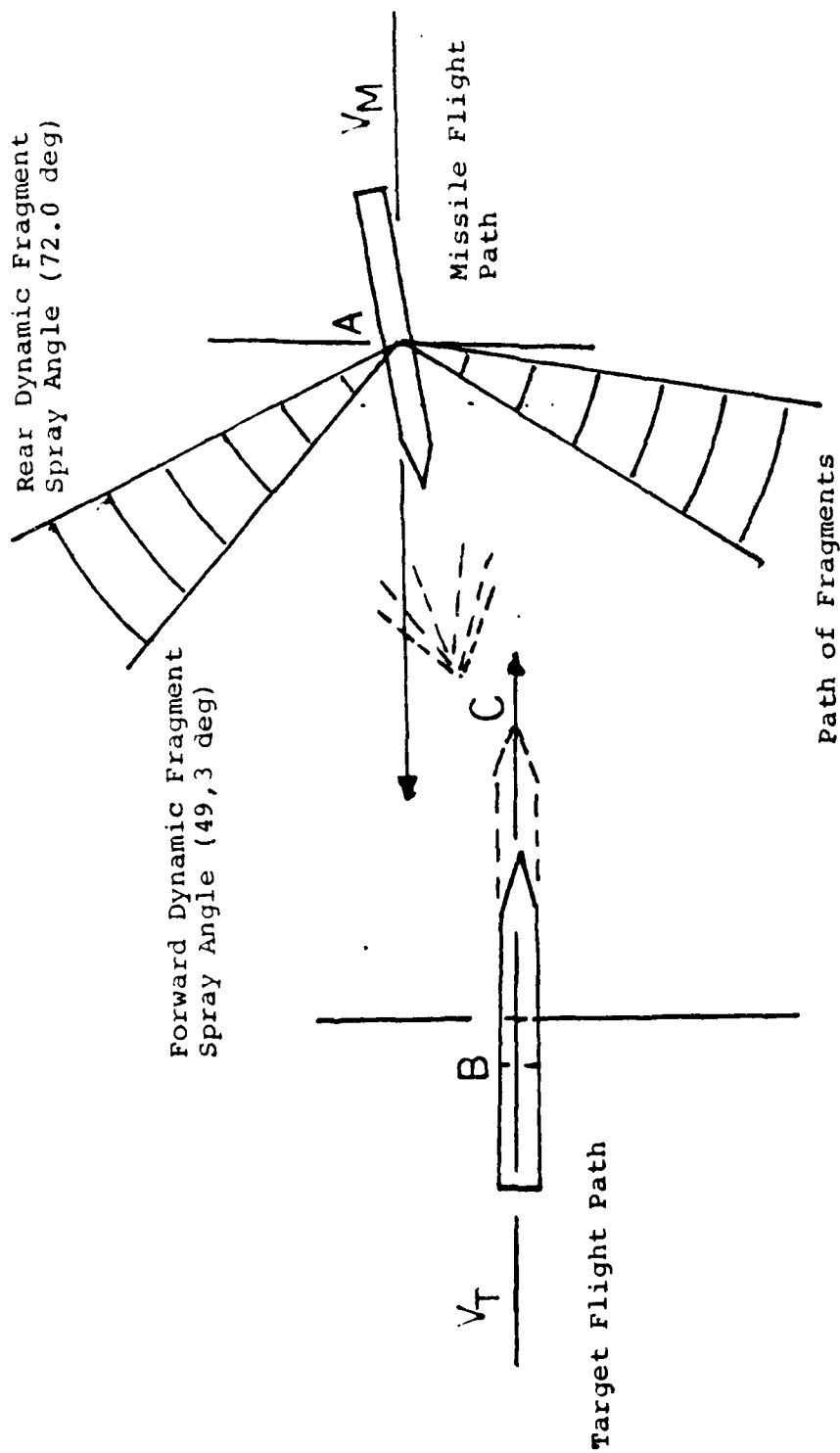


Figure 7. Single Encounter

of polar zones will become skewed. It is assumed that at the time of detonation the missile is at point "A" on the indicated flight path traveling with velocity V_m and that the target is at point "B" on the indicated flight path and has velocity V_t . At the time of detonation the missile is at point "A" and the explosives are detonated yielding fragments whose velocities are 5,180 fps, (it is assumed that the fragment pattern is symmetric about the axis of the missile). A fragment, projected at angle θ is seen to miss the target at point "C". However, the fuze detonates the warhead before the missile reaches the target; thus debris from the forward part of the missile and propulsion section are driven forward at high velocity by the explosion. This debris strikes the target in a vulnerable area causing structural damage or fuel fires. The SCAN program assumes that the debris will continue along the original missile trajectory with the same velocity as the missile. This is assumed to provide program simplicity, since in actuality the debris is accelerated by the explosive and may travel on slightly different trajectories.

C. P_k VS MISS DISTANCE WITH INCREASING EXPLOSIVE WEIGHTS

The target used contains six major systems which will define the target kill probability. Figure 8 deals primarily with K-kill against the cruise missile target without regard to the probability of blast or direct hit; therefore, the analysis given here indicates the effectiveness of a 105

grain fragmentation warhead in a head-on encounter condition, with increasing explosive weight.

In order to minimize the computer time, the number of curves generated for design was held to three. In Figure 8, reading from left to right, the probability of kill is 100% at 30 feet, for a warhead explosive weight of 18.3 lbs., but decreases to zero at 60 feet. Continuing to the right, holding the same grain size and l/d ratio, but increasing the warhead radius (allowing more explosive weight and more fragments) the probability of kill will increase for a given miss distance in relation to curve number one.

D. WARHEAD RADIUS VS P_k

An increase in warhead radius (holding case thickness and l/d constant) results in an increase in number of fragments, and allows for an increase in C/M ratio which results in an increase of fragment velocity. This relationship has been noted in Figure 9. Observing the 50 foot miss distance curve line in that figure, and starting with a warhead radius of 3 inches, the probability of kill is approximate 47%. Moving up the 50 foot curve line by increasing the warhead radius to 4 inches, results in an increase in P_k to approximately 92%. As the radius increases, the P_k finally reaches 100% at approximately 5 inches, illustrating that this is the optimum diameter for the warhead to achieve its purpose against a generic cruise missile target.

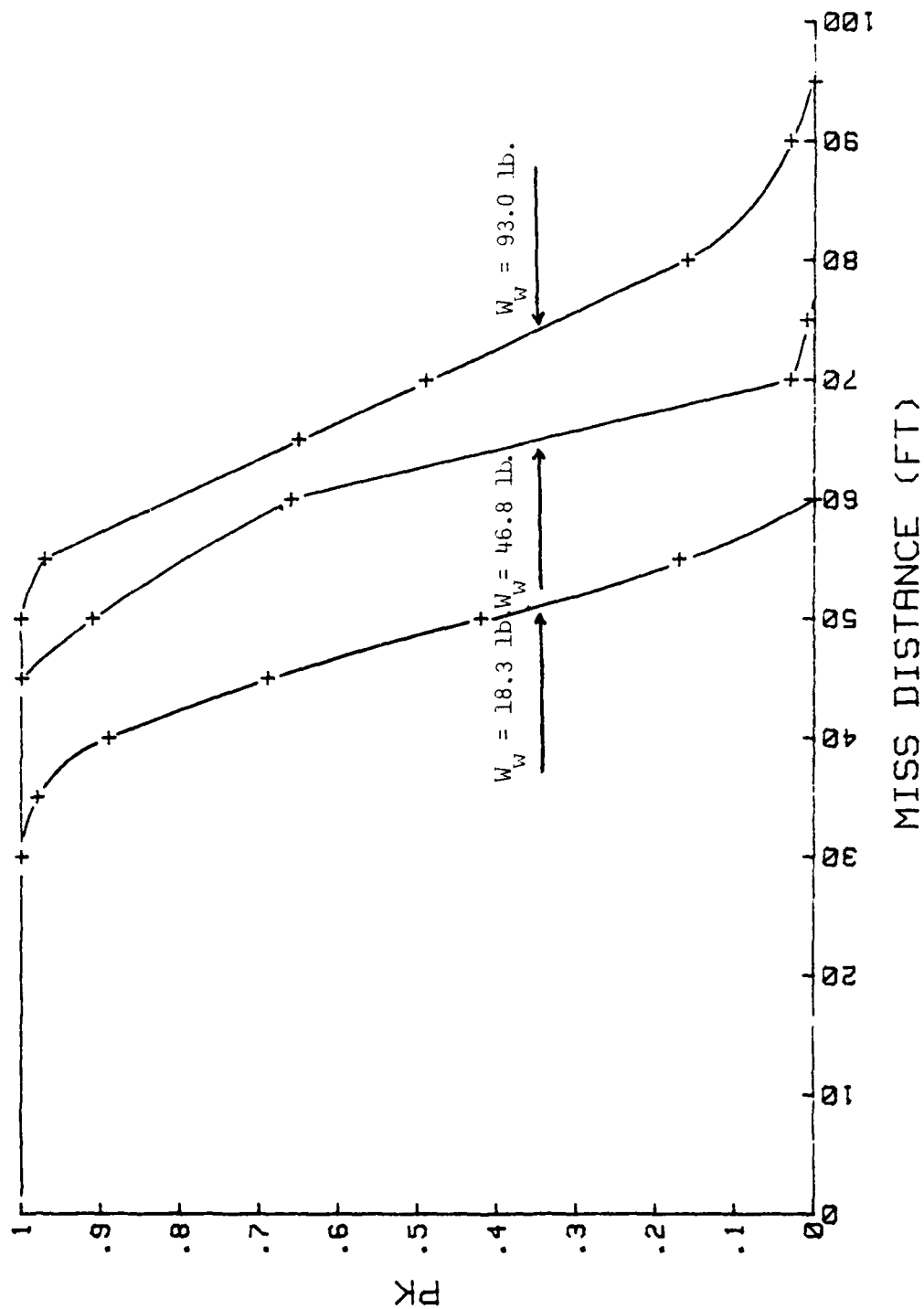


Figure 8. P_k vs. Miss Distance with Increasing Explosive Weight.

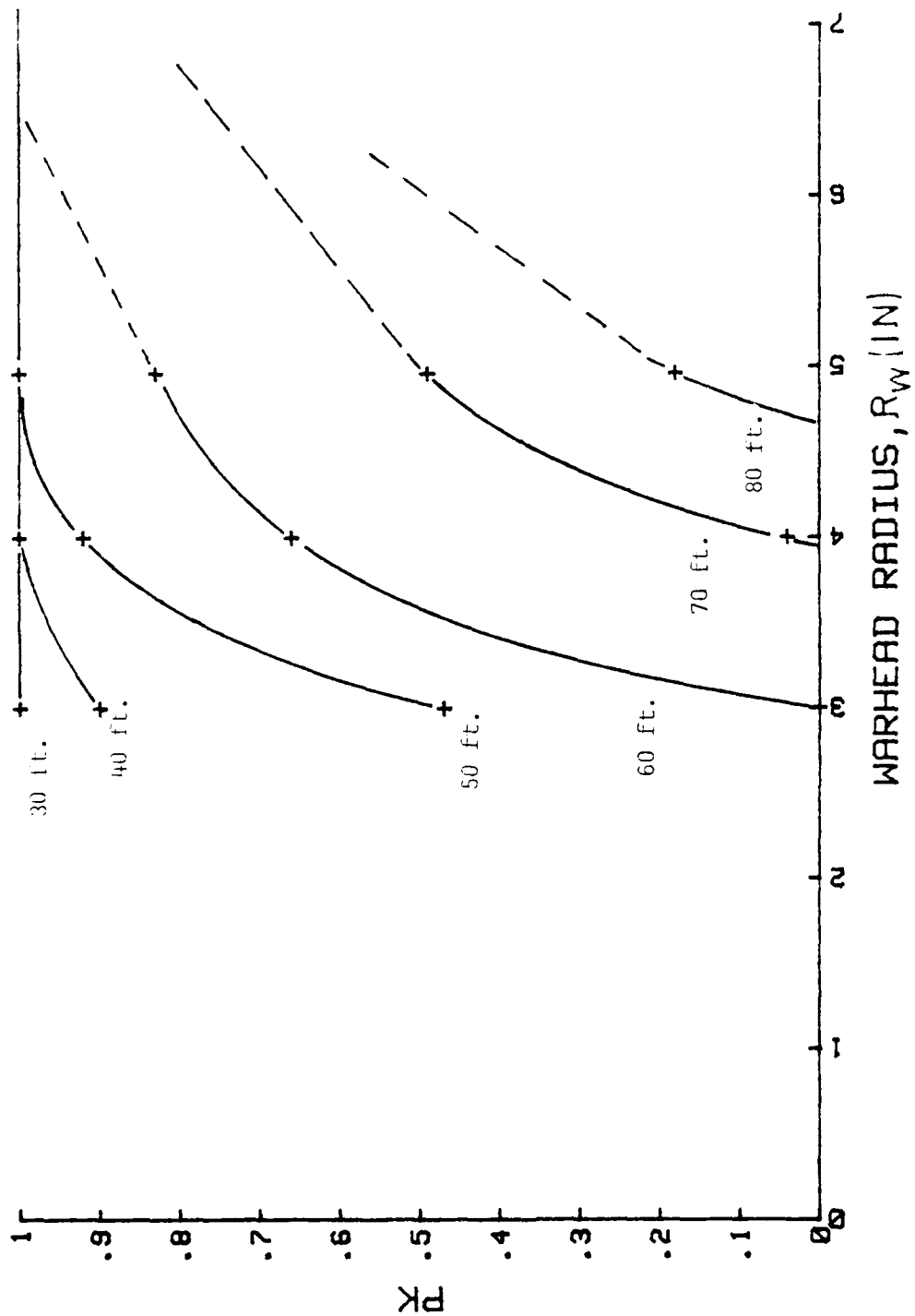


Figure 9. Warhead Radius vs. P_k .

E. WARHEAD TRIGGERING POSITION AS A PARAMETER

In Figure 10, for an 18.3 lb. warhead, the warhead kill probability was plotted against miss distance. All encounter conditions were head-on, at an altitude of 10,000 feet, with a miss distance of up to 50 feet and the warhead triggering position as the parameter. The angle of attack of the missile was varied with a standard deviation of 3.0 degrees, the elevation angle had a standard deviation of 1.0 degrees, and the azimuth angle had a standard deviation of 1.0 degree.

Curves were made for various positions of warhead detonation relative to the target. Obviously not every warhead fired will hit the target, but the warhead will have a miss distance probability distribution for any given target. For each specific target type, the warhead will exhibit a kill probability vs. miss distance distribution which is dependent upon some of the following target characteristics: size, shape, velocity and vulnerability.

In order to arrive at an average P_k for constructing Figure 10, the triggering position was moved various distances fore and aft of the center of gravity of the missile, with a miss distance along the trajectory of the flight path of the target of from 30 to 50 feet.

To develop each detonation position curve fore and aft of the CG, there were 50 encounter condition simulations run with the standard deviations in azimuth angle, elevation angle and angle of attack mentioned above. To derive the

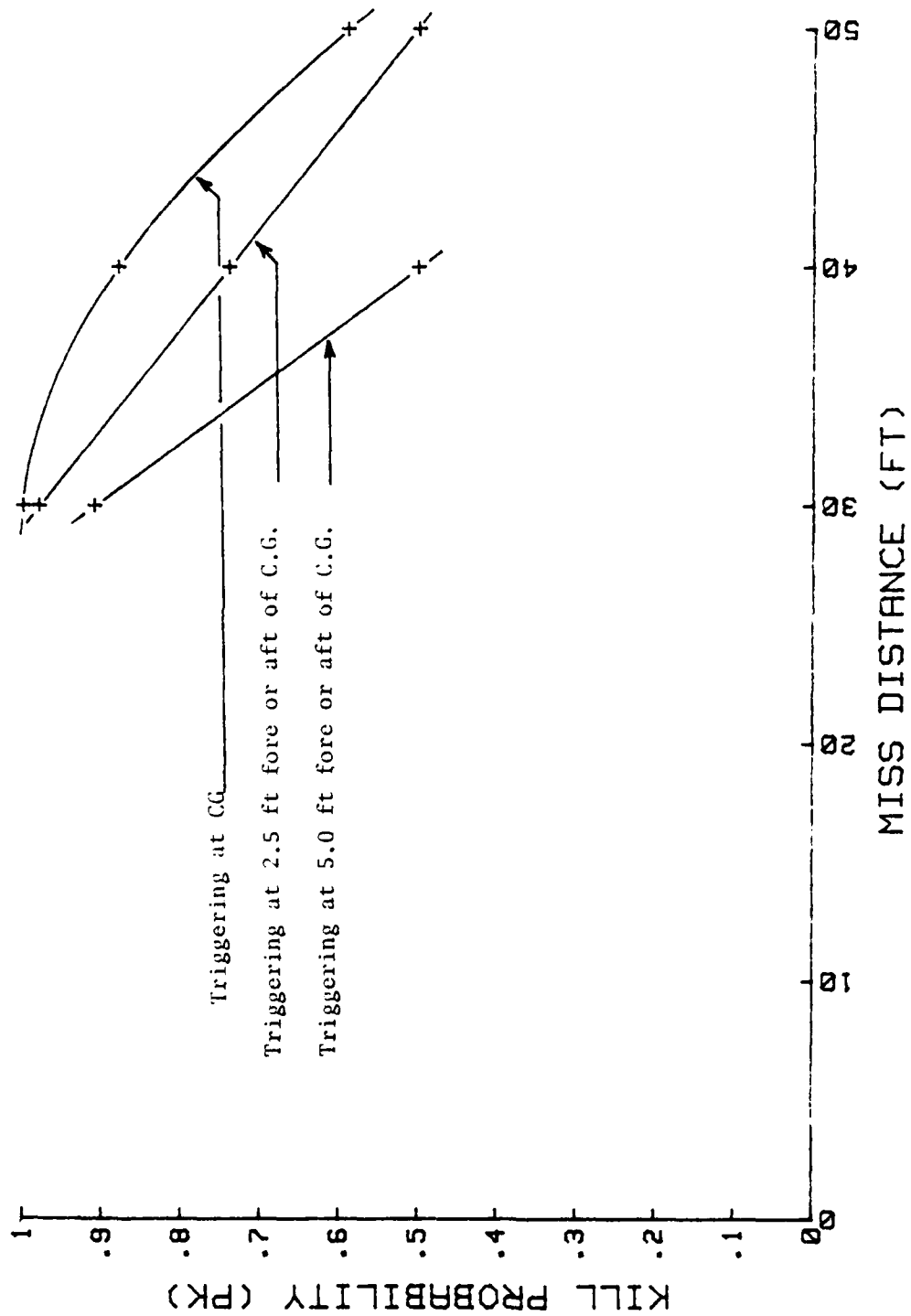


Figure 10. Warhead Triggering Position as a Parameter.

average P_k , the fore and aft positions were averaged, resulting in a P_k along the trajectory.

In observing Figure 10 at the 2.5 foot fore and aft curve line, the results show that at a miss distance of approximately 40 feet from the target the P_k is approximately 75%. In Figure 11, it is noted that if the triggering position is moved further aft the average P_k decreases. This is because the kill probability in the aft position decreases rapidly due to the spray pattern from the warhead no longer covering the target sufficiently to destroy it.

The average P_k is effected radically by a small time deviation in the triggering device, along with the static spray angles and the encounter conditions. When the fuzing accuracy is known, it should be taken into consideration in order to correctly estimate the fragment spray pattern that will cover the target in the case of early or late detonations.

1. Triggering at 10 ft forward of CG
2. Triggering at 5 ft. forward of CG
3. Triggering at 5 ft. aft of CG

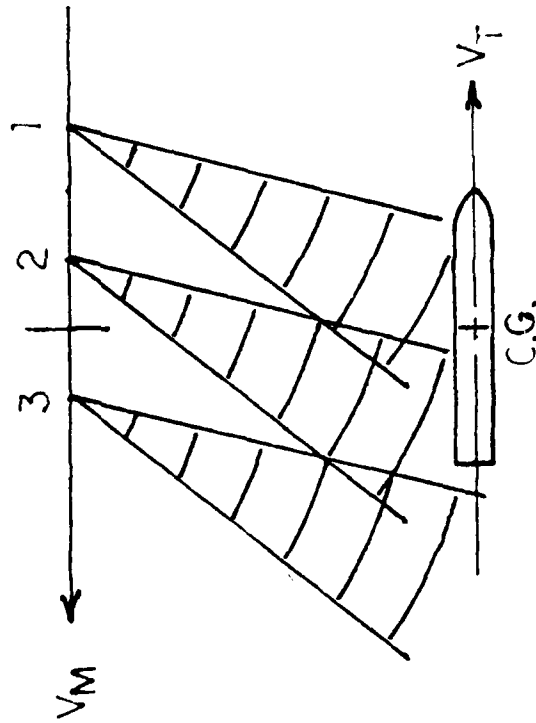


Figure 11. Triggering Positions.

F. EVALUATION OF FRAGMENT SIZE

In choosing the optimum fragment size against aerial targets, the several factors must be considered. The missile is likely to operate over a range of altitudes, and very small fragments, optimum at high altitudes, are nearly useless at low altitudes, due to a high drag coefficient on the fragment, except for very small miss distances.

The target has a major influence on fragment size. The skin thickness around vital components varies considerably between different targets. The warhead designer normally knows only the probable thicknesses of skins of the target. For example, effectiveness of very small fragments against jet engines can be discounted in most cases due to the high strength steels and titanium used in jet engine parts. In a given warhead volume, the smaller the individual fragment, the greater the number of fragments that are possible. For its effectiveness, the smaller fragment requires a higher velocity and therefore a greater Charge to Mass (C/M) ratio.

Although there is no simple answer that can be given for selecting optimum fragment size and striking velocity because of the complexity of the damage criteria, information from test results can be used to assist in selecting the optimum fragment size.

Rectangular fragments of 60 to 240 grains were used with a striking velocities from 1,000 to 7,000 feet per second. Increasing the number of fragments (resulting in smaller

fragments) increased the probability of at least one hit on an individual component of the target, but at the same time, reduced the probability of a catastrophic kills.

In the end, the optimum warhead is a compromise that also involves detonation distance and the encounter conditions with the target. By referring to Figures 12, 13 and 14 and taking into consideration that the cruise missile is a soft target relative to a bomber or fighter due to the lack of redundancy in components and systems, it is apparent that a 60 grain fragment size is the most effective against the target.

To further assist the designer, the fragment initial velocities computed by Gurney's equation

$$V_i = \sqrt{2E} \left[\frac{C/M}{1 + C/2M} \right]^{1/2}$$

for a solid cylinder are plotted against C/M. The initial velocity of a fragment (V_i) depends on two factors: (a) the charge to mass ratio or C/M, and (b) the characteristic of the explosive material. Figure 15 illustrates the relationship between the charge to mass ratio and the initial velocities, (V_i), of the fragments, as determined from Gurney's equation. The curves shown were plotted for three explosives: Composition B, TNT, and HMX. With range in warhead size considered from 2.6 to 4.6 inch internal diameter and a uniform case thickness of 0.4 inches, the C/M ratio varied from 0.6 to 1.1. The initial velocities which resulted are shown

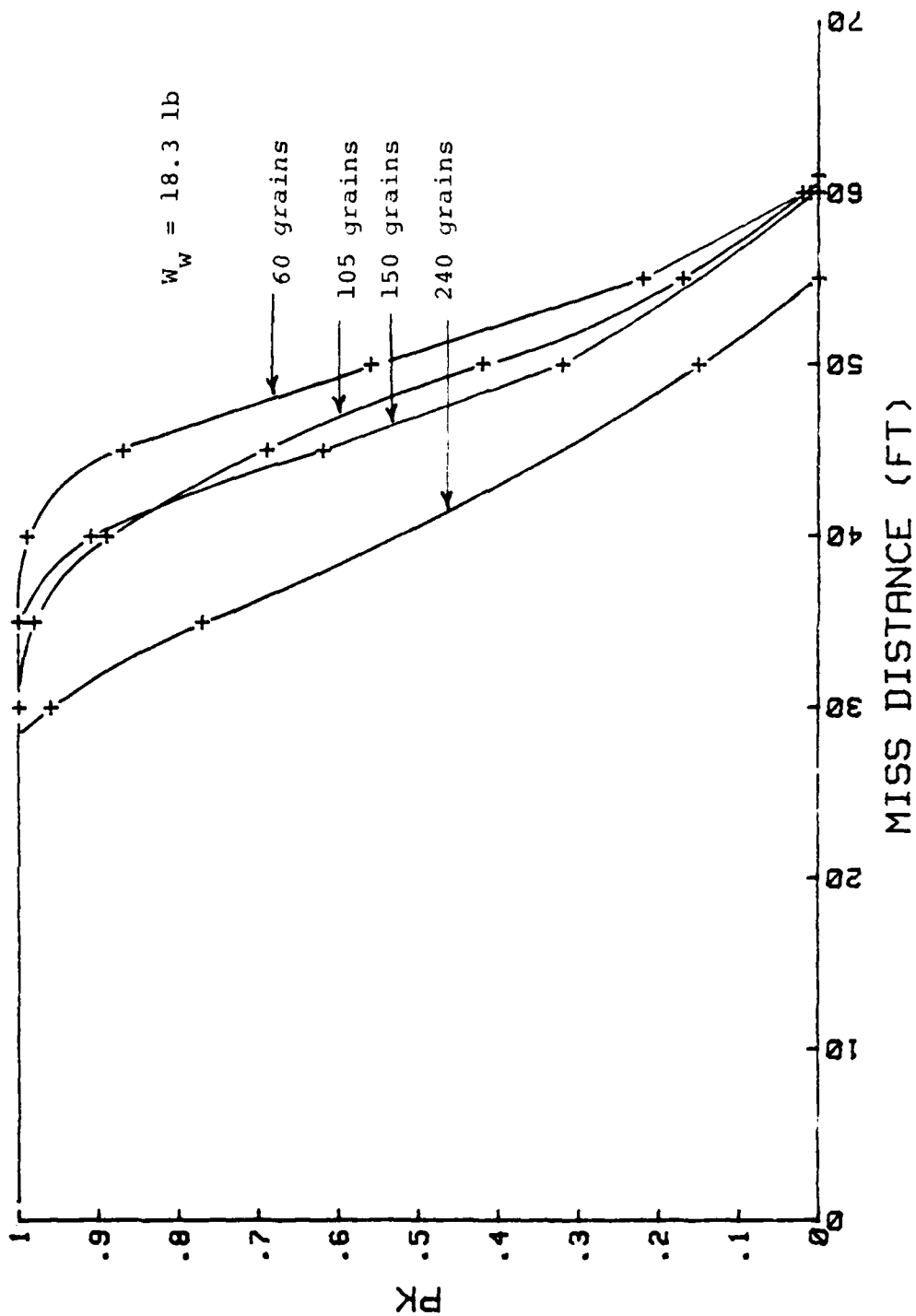


Figure 12. Warhead Explosive Weight - 18.3 lb.

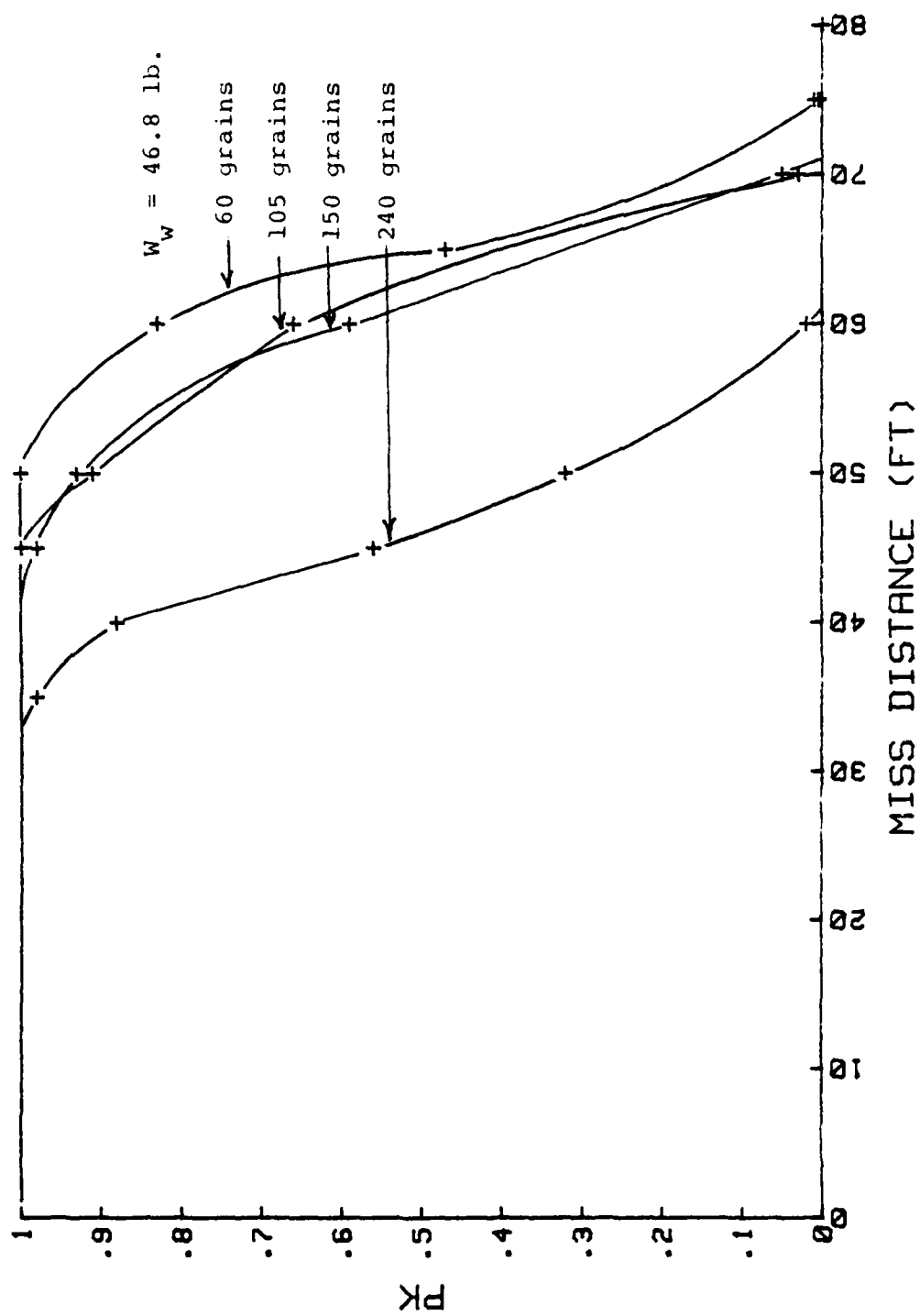


Figure 13. Warhead Explosive Weight = 46.8 lb.

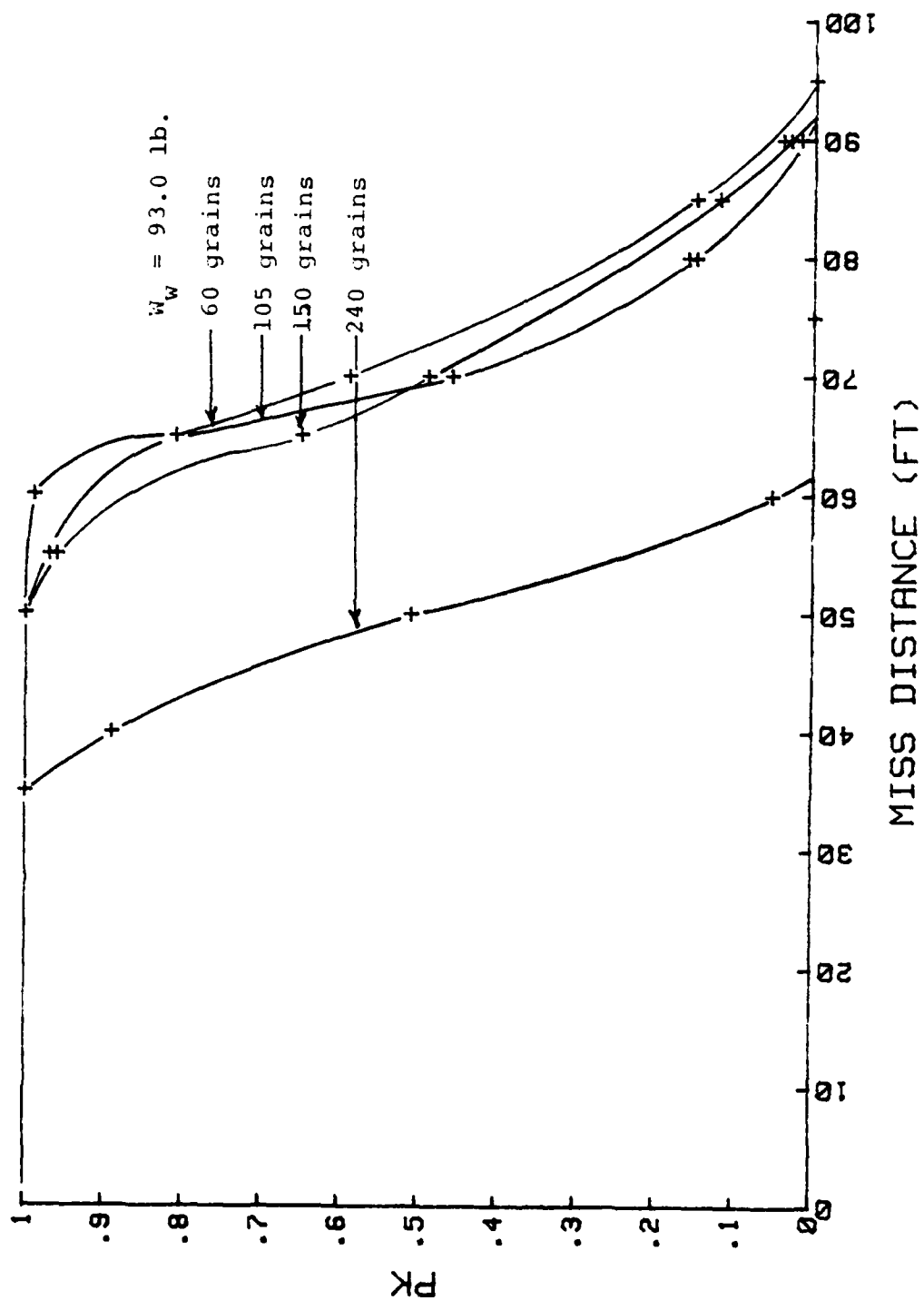
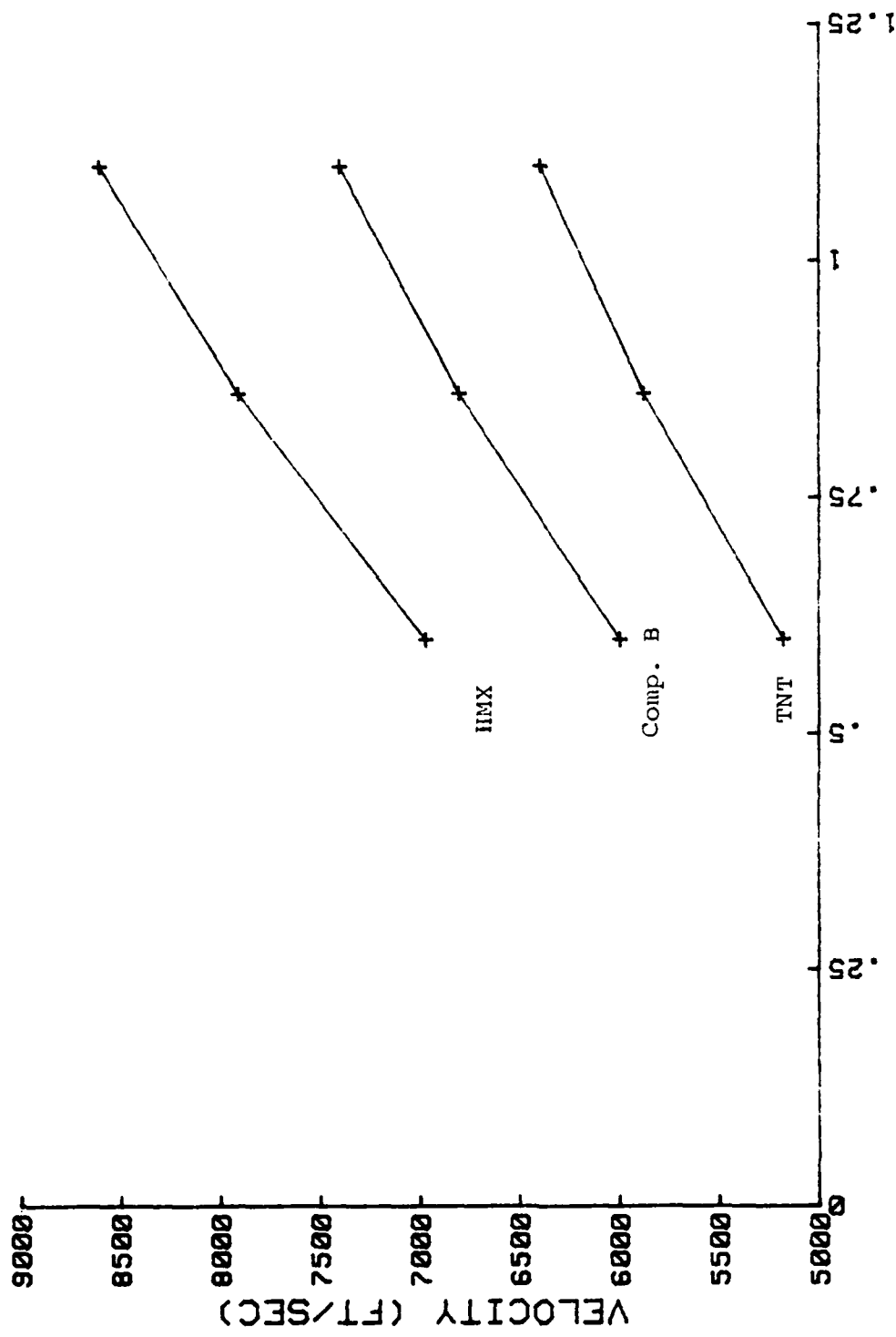


Figure 14. Warhead Explosive Weight = 93.0 Lb.



CHARGE-TO-MASS RATIO

Figure 15. Velocity vs. Charge to Mass Ratio.

in Figure 15. The designer should be aware that the initial fragment velocity obtained in this formula is the maximum possible value. Lower values are found near the ends of the cylindrical warhead, due to the geometric shape of the warhead.

V. CONCLUSION

The complete determination of the kill probability of a particular type of target by a given warhead for even a single altitude and aspect, and with fixed intercept velocities, is an enormous task. It is not possible to give a single number or formula for all the factors considered in the study, which would represent the overall relative effectiveness of the fragmentation warhead. This investigation was carried out with the aid of the SCAN computer program, but even this limited investigation generated hundreds of computer pages of data. After analysis of this data, the warhead designer still has only a description of the performance of a given warhead under very limited conditions. However, it seems clear that a relative lethality is possible through such a study, at least giving the designer a feel for how well a particular type of warhead could perform under certain circumstances. The problem of designing and constructing an optimum performance warhead through the use of computer data analysis is still largely unsolved. Nevertheless, computer data analysis is a helpful tool for the warhead designer, since it can give guidance on the selection of many of the crucial parameters that will make the warhead effective against a given target.

As computer programs such as SCAN and ATTACK evolve and improve, the data produced by these simulated encounter conditions between warhead and target will tend more and more to realistically reflect and match the actual results of test situations. This should result in a great cost savings to the designer, since it should be possible to reduce the number of expensive tests.

At the present time, the SCAN program library of targets is quite limited, but as the library expands, so will the usefulness of the program expand to those persons interested in studying missile warhead design.

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